(12) UK Patent Application (19) GB (11) 2 279 213 (13) A

(43) Date of A Publication 21.12.1994

(21) Application No 9401790.2

(22) Date of Filing 31.01.1994

(30) Priority Data
(31) 05143349 (32) 15.06.1993 (33) JP

(51) INT CL^5
H04L 27/14 5/06

(52) UK CL (Edition M)
H4P PAFD
U1S S2205

(56) Documents Cited
None

(58) Field of Search
UK CL (Edition M) H4L LDB, H4P PAFD PAL
INT CL^5 H04L 27/14

(71) Applicant(s)
Fujitsu Limited

(Incorporated in Japan)

1015 Kamikodanaka, Nakahara-ku, Kawasaki-shi, Kanagawa 211, Japan

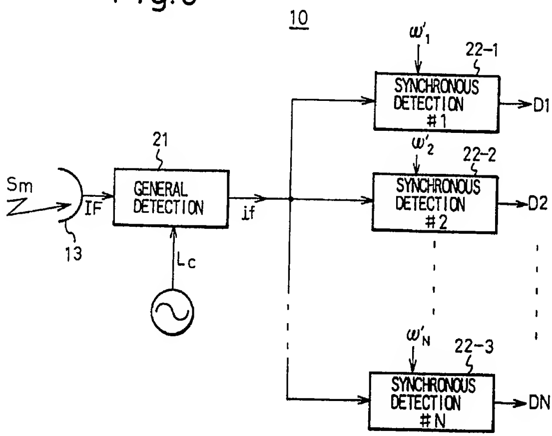
(72) Inventor(s)
Kenzo Kobayashi

(74) Agent and/or Address for Service
Haseltine Lake & Co
Hazlitt House, 28 Southampton Buildings, Chancery Lane, LONDON, WC2A 1AT, United Kingdom

(54) Demodulator for multi-carrier signals

(57) A demodulator 10, for demodulating multi-carrier modulation signals, includes a general detection unit 21, employing a common local frequency signal Lc to detect the multi-carrier modulation signal Sm commonly for all channels, and N synchronous detection units 22 for performing synchronous detection by means of respective reference signals ω, having frequencies equal to the differences between the frequencies of the carriers of the multi-carrier modulation signal, on the one hand, and the frequency of the common local frequency signal, on the other hand, so as to reproduce the original data. The hardware of such a demodulator can be made conveniently small in size since it is no longer necessary to employ a demodulator for each signal frequency as in the prior art [fig. 2].

Fig.3



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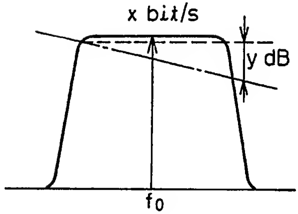


Fig.1A SINGLE CARRIER

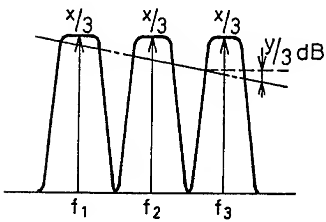


Fig.1B MULTI-CARRIER

Fig. 2

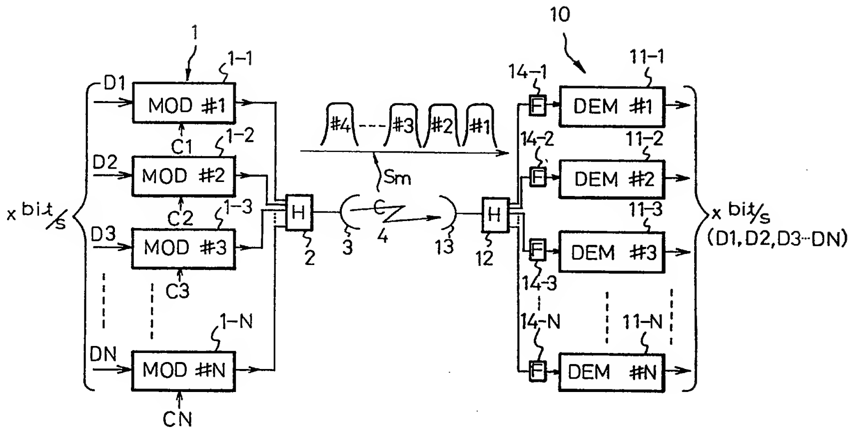

1
1-1
D1
MOD #1
C1
1-2
D2
MOD #2
C2
1-3
D3
MOD #3
C3
1-N
DN
MOD #N
CN
x bit/s
H
2
3
4
13
12
Sm
#4 --- #3 #2 #1
10
14-1
14-2
14-3
14-N
F
DEM #1
DEM #2
DEM #3
DEM #N
11-1
11-2
11-3
11-N
x bit/s
(D1, D2, D3···DN)

Fig.3

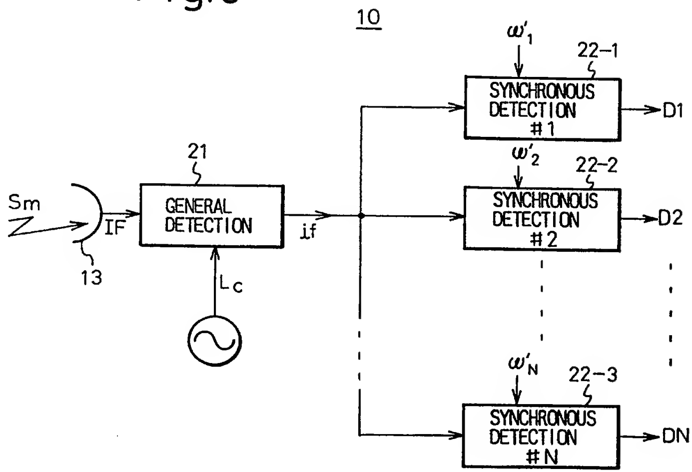

10
Sm
13
IF
21
GENERAL DETECTION
Lc
if
ω'1
22-1
SYNCHRONOUS DETECTION #1
D1
ω'2
22-2
SYNCHRONOUS DETECTION #2
D2
ω'N
22-3
SYNCHRONOUS DETECTION #N
DN

Fig.4

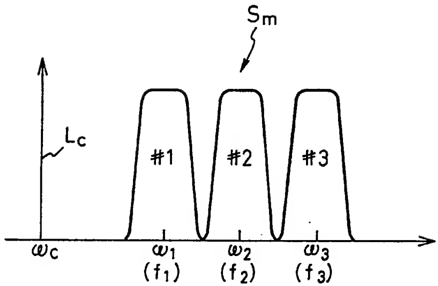
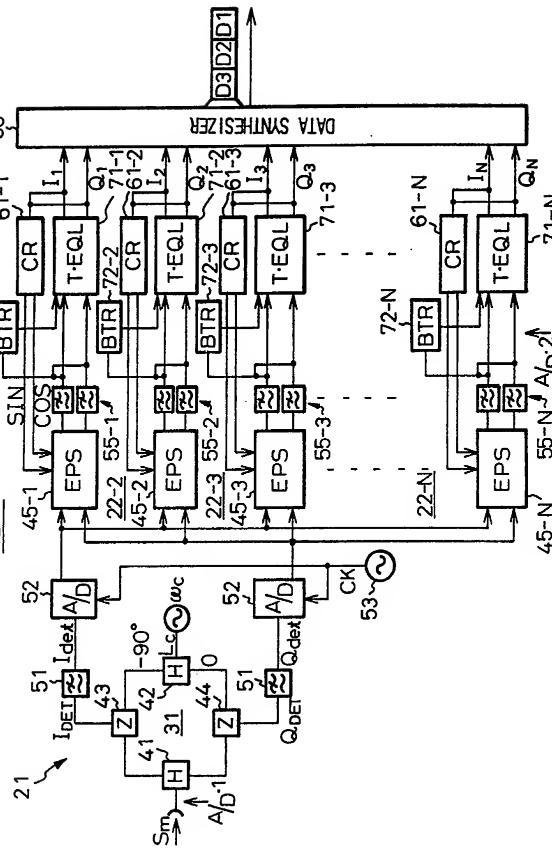
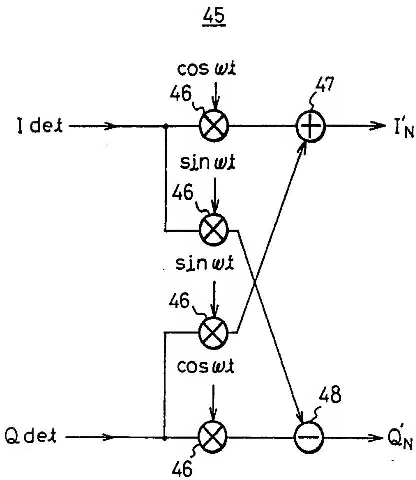


Fig.5



DATA SYNTHESIZER
D3
D2
D1
56
CR
T·EQL
BTR
EPS
SIN
COS
A/D
CK
H
Z
61-1
61-2
61-3
61-N
71-1
71-2
71-3
71-N
72-1
72-2
72-3
72-N
55-1
55-2
55-3
55-N
45-1
45-2
45-3
45-N
22-1
22-2
22-3
22-N
52
53
51
41
42
43
44
31
21
Sm
Lc
ωc
-90°
0
I_DET
Q_DET
I_det
Q_det
I_1
Q_1
I_2
Q_2
I_3
Q_3
I_N
Q_N
A/D·1
A/D·2

Fig. 6



DEMODULATOR FOR MULTI-CARRIER SIGNALS

The present invention relates to demodulators for multi-carrier signals.

In digital multiplex radio communication and other radio communication systems, technology for compensating for propagation path distortion caused by fading etc. in the radio transmission space is highly desirable. Various proposals for this have already been made, including space diversity and transversal equalizers.

On the other hand, the multi-carrier method has been proposed for practical use as a technology for raising the tolerance against propagation path distortion and improving line quality. Hitherto, the single carrier method has been in wide use.

As will be explained later in more detail with reference to the accompanying drawings, a multi-carrier communication system may operate as follows: In a multi-carrier modulator of the transmitter, data sets (D1, D2, ... DN) obtained by dividing an original data sequence into N sets of data (N being an integer equal to 2 or more), are used respectively to modulate N carrier signals (C1, C2, ... CN) by modulation units, in one to one correspondence. The multi-carrier modulated signal obtained by combining these modulated carrier signals in a hybrid circuit is transmitted from an antenna of the transmitter and received at an antenna of the receiver. The multi-carrier modulated signal is then separated by a hybrid circuit and the results demodulated by multi-carrier modulation signal demodulator means to reproduce the original data.

The required multi-carrier modulation signal demodulator means can be made up of a plurality of demodulation units corresponding respectively to the modulation units. However, such multi-carrier modulation signal demodulator means require an

inconveniently large amount of hardware.

An embodiment of the present invention can provide a demodulator which includes a general detection unit, for detecting the multi-carrier modulation signal from the transmitter side generally and commonly for all N channels, and N number of synchronous detection units for performing synchronous detection by differential frequencies equal respectively to the differences between the carrier frequencies of the multi-carrier modulation signal on the one hand, and on the other hand, a common local frequency signal, so as to reproduce the original data.

Reference will now be made, by way of example, to the accompanying drawings, in which:

Figures 1A and 1B are diagrams for explaining the multi-carrier method in comparison with the single carrier method;

Figure 2 is a schematic block diagram of a communication system using the multi-carrier method but not embodying the present invention;

Figure 3 is a schematic block diagram of a demodulator embodying the present invention;

Figure 4 is a frequency spectrum diagram;

Figure 5 is a block diagram of a demodulator embodying the present invention;

Figure 6 is a schematic diagram showing details of one example of an endless phase shifter.

Figures 1A and 1B are views for explaining a multi-carrier method in comparison with a single carrier method. Figure 1A shows the frequency spectrum in the case of a single carrier method in which a single carrier signal (frequency f_0) is modulated by transmission data having a bit repetition rate of x bits/s.

On the other hand, Figure 1B shows the frequency spectrum in the case of a multi-carrier method in which

N (N being an integer not less than 2, the case of N = 3 being shown in the figure) sets of data (each having a bit repetition rate of x/3 bits/s) and used to modulate N (N = 3) carrier signals (having frequencies of f_1, f_2, and f_3) in one-to-one correspondence.

The biggest advantage obtained by use of the multi-carrier method is that the tolerance of propagation path distortion is improved and line quality can be tremendously improved. In Figures 1A and 1B, assume that there is a fading effect and that an inclination (shown by dot-chain line) appears in the frequency characteristic. Assume that the interband deviation caused by this inclination appears as y dB in the single carrier method (Fig. 1A). In the case of exactly the same inclination as this, in the multi-carrier method (Fig. 1B), only a deviation of y/3 dB occurs in each of the frequency bands having the different carrier frequencies (f_1, f_2 and f_3) as centre frequencies. In such a case, in the multi-carrier method (Fig. 1B) the tolerance to fading is three times greater than with the single carrier method (Fig. 1A).

Figure 2 shows a communication system using a multi-carrier method. The left-hand side of the Figure shows the transmitter and the right-hand side shows the receiver, which comprises a multi-carrier modulation signal demodulator 10.

In a multi-carrier modulator 1 of the transmitter, data sets D1, D2, ...DN, each having bit repetition rates of x bits/s, obtained by dividing an original data sequence into N sets of data (N being an integer of 2 or more), are used by modulation units 1-1, 1-2, ... 1-N) to modulate N carriers C1, C2, ... CN respectively, in one-to-one correspondence. The multi-carrier modulation signal S_m obtained by combining these modulated carriers in a hybrid circuit 2 is transmitted into a radio transmission space 4 from an

antenna 3 of the transmitter and received at an antenna 13 of the receiver. The received multi-carrier modulation signal is then separated in a hybrid circuit 12 and the results demodulated in the multi-carrier modulation signal demodulator 10 to reproduce the original data sequence.

The multi-carrier modulation signal demodulator 10 includes N demodulation units 11-1, 11-2, ... 11-N corresponding respectively to the modulation units 1-1, 1-2, ..., 1-N of the transmitter.

The frequency spectrum of the multi-carrier modulation signal S_m, corresponding to Fig. 1B, is shown in Fig. 2 above the radio transmission space 4. Fig. 2 also shows band-pass filters (F) 14-1, 14-2, ... 14-N for extracting the carrier modulation signals (#1, #2, ... #N).

From the outputs of all the demodulation units (11), it is possible to reproduce the original data sequence D1, D2,....DN.

The multi-carrier modulation signal demodulator 10 as shown in Fig. 2 gives improved tolerance with respect to fading, but needs, compared with a conventional signal carrier method, N times the amount of hardware, corresponding to the number of carriers C_1, C_2, ... CN employed.

An embodiment of the present invention can provide a multi-carrier modulation signal demodulator with significantly less hardware than that required in the Fig. 2 system.

Figure 3 is a block diagram showing the basic constitution of an embodiment of the present invention, which embodiment employs intermediate detector circuitry acting as a general detection means 21 and N synchronous detection states 22-1, 22-2,....22-N. The received multi-carrier modulation signal S_m is generally detected by means of a common local frequency

signal L_C at the general detection means 21. The output from the general detection means 21 is received in common by N synchronous detection stages 22-1, 22-2,....22-N. Synchronous detection is performed with the aid of N differential reference signals having frequencies equal to the differences between the frequencies of the N carriers C1, C2, ...CN, on the one hand, and the frequency of the common local frequency signal L_C on the other hand. Sets of data D1, D2, ... Dn are reproduced respectively by the N synchronous detection means 22-1, 22-2,....22-N.

A look at the detectors required for the initial stage of processing at the receiver side, that is, the detecting operation, shows that in the Figure 2 system N detectors are required corresponding to the carriers C1, C2, ...CN, whereas in the Figure 3 embodiment this can be realised by a single general detection means 21, so the hardware for this part of the system is reduced by a factor of 1/N.

Before explaining further the illustrated embodiment of the present invention, a more detailed explanation will be given of its principles of operation. Note that this explanation will be made taking as a preferred example the case of reception of quadrature phase shift keying signals (orthogonal modulation) in a three-carrier method. However, it may alternatively be applied to a case of reception of binary phase shift keying signals, or a case of reception of 8-phase, 16-phase, or other phase shift keying signals.

Figure 4 .shows a frequency spectrum of a

multi-carrier modulation signal S_m in a three-carrier system, wherein the first modulation signal having the first carrier C1 (angular frequency ω_1) as its center frequency is shown by #1 and similarly the second and third modulation signals, having the second and third carriers C2 and C3 (angular frequencies W_2 and W_3) respectively as their center frequencies, are shown by #2 and #3.

The angular frequency of the common local frequency signal L_c employed in the general detection means 21 shown in Fig. 3 is shown as ω_C.

Further, in Fig. 2, the orthogonal modulation data output from the modulation units (1-1, 1-2, and 1-3) on the transmitter side, that is, the I (In-phase) ch (Channel) data I and Q (Quadrature-phase) ch data Q, are expressed as I_1, Q_1; I_2, Q_2; I_3, Q_3 and the time as t.

The first, second and third modulation signals (#1, #2 and #3) can be expressed by the following equations (1), (2) and (3):

$$\#1 = I_1 \sin\omega_1 t + Q_1 \cos\omega_1 t \qquad (1)$$

$$\#2 = I_2 \sin\omega_2 t + Q_2 \cos\omega_2 t \qquad (2)$$

$$\#3 = I_3 \sin\omega_3 t + Q_3 \cos\omega_3 t \qquad (3)$$

The multi-carrier signal transmitted from the transmitter through the radio transmission space 4 and received by the receiver can be expressed by the following equation (4): However, this is shown as a received signal IF obtained after conversion to a lower frequency by a down converter.

$$IF = \#1 + \#2 + \#3 \qquad (4)$$

If this received signal IF is given to the general detection means 21 of Fig. 3, it is generally detected by the common local frequency signal L_C. Therefore, the orthogonal demodulation signals I_{DET} and Q_{DET} orthogonally detected with the angular frequency ω_C are expressed by

the following equations (5) and (6), respectively, as I_{DET} = IF x $\sin\omega_C t$ and Q_{DET} = IF x $\cos\omega_C t$:

$$I_{DET} = (\#1+\#2+\#3)\sin\omega_C t$$
$$= I_1\sin\omega_1 t\sin\omega_C t+Q_1\cos\omega_1 t\sin\omega_C t$$
$$+I_2\sin\omega_2 t\sin\omega_C t+Q_2\cos\omega_2 t\sin\omega_C t$$
$$+I_3\sin\omega_3 t\sin\omega_C t+Q_3\cos\omega_3 t\sin\omega_C t$$
$$= 0.5[\{I_1(-\cos(\omega_1+\omega_C)t+\cos(\omega_1-\omega_C)t)$$
$$+Q_1(\sin(\omega_1+\omega_C)t-\sin(\omega_1-\omega_C)t)\}$$
$$+\{I_2(-\cos(\omega_2+\omega_C)t+\cos(\omega_1-\omega_C)t)$$
$$+Q_2(\sin(\omega_1+\omega_C)t-\sin(\omega_1-\omega_C)t)\}$$
$$+\{I_3(-\cos(\omega_3+\omega_C)t+\cos(\omega_3-\omega_C)t)$$
$$+Q_3(\sin(\omega_3+\omega_C)t-\sin(\omega_3-\omega_C)t)\} \qquad (5)$$

$$Q_{DET} = (\#1+\#2+\#3)\cos\omega_C t$$
$$= I_1\sin\omega_1 t\cos\omega_C t+Q_1\cos\omega_1 t\cos\omega_C t$$
$$+I_2\sin\omega_2 t\cos\omega_C t+Q_2\cos\omega_2 t\cos\omega_C t$$
$$+I_3\sin\omega_3 t\cos\omega_C t+Q_3\cos\omega_3 t\cos\omega_C t$$
$$= 0.5[\{I_1(\sin(\omega_1+\omega_C)t+\sin(\omega_1-\omega_C)t)$$
$$+Q_1(\cos(\omega_1+\omega_C)t+\cos(\omega_1-\omega_C)t)\}$$
$$+\{I_2(\sin(\omega_2+\omega_C)t+\sin(\omega_2-\omega_C)t)$$
$$+Q_2(\cos(\omega_2+\omega_C)t+\cos(\omega_2-\omega_C)t)\}$$
$$+\{I_3(\sin(\omega_3+\omega_C)t+\sin(\omega_3-\omega_C)t)$$
$$+Q_3(\cos(\omega_3+\omega_C)t+\cos(\omega_3-\omega_C)t)\} \qquad (6)$$

From the above equation (5) expressing I_{DET}, a low-pass filtered demodulation signal I_{det} from which the high frequency component $(\omega_N+\omega_C)$ (N=1, 2, and 3) has been removed is produced next. Similarly, from the above equation (6) expressing Q_{DET}, a low-pass filtered demodulation signal Q_{det} from which the high frequency component $(\omega_N+\omega_C)$ (N=1, 2, and 3) has been removed is produced next. The thus produced low-pass filtered demodulation signals I_{det} and Q_{det} can be expressed by the following equations (7) and (8):

$$Q_{det} = 0.5\ [\{I_1\sin(\omega_1-\omega_C)t+Q_1\cos(\omega_1-\omega_C)t\}$$
$$+\{I_2\sin(\omega_2-\omega_C)t+Q_2\cos(\omega_2-\omega_C)t\}$$
$$+\{I_3\sin(\omega_3-\omega_C)t+Q_3\cos(\omega_3-\omega_C)t\}] \qquad (7)$$

$$I_{det} = 0.5\ [\{I_1\cos(\omega_1-\omega_C)t-Q_1\sin(\omega_1-\omega_C)t\}$$
$$+\{I_2\cos(\omega_2-\omega_C)t-Q_2\sin(\omega_2-\omega_C)t\}$$
$$+\{I_3\cos(\omega_3-\omega_C)t-Q_3\sin(\omega_3-\omega_C)t\}] \quad (8)$$

The angular frequencies shown here are $\omega_1-\omega_C$, $\omega_2-\omega_C$, and $\omega_3-\omega_C$ and are shifted by exactly ω_C from the angular frequencies (ω_1, ω_2, and ω_3) of the original carriers C1, C2, and C3. Therefore, for the low-pass filtered demodulation signals I_{det} and Q_{det}, in the first, second, and third synchronous detection means 22-1, 22-2, and 22-3, synchronous detection is performed to decode I_1, Q_1; I_2, Q_2; I_3, Q_3 and reproduce the corresponding original data D1, D2, and D3. Note that the synchronous detection means (22) are preferably comprised of endless phase shifters (EPS).

From the synchronous detection means (EPS) 22-1, 22-2, and 22-3 are output the channel-corresponding orthogonal decoded data I_1', Q_1'; I_2', Q_2'; I_3', Q_3'. Here, the channel-corresponding orthogonal decoded data of the three channels are expressed together as I_N' and Q_N'. N is 1, 2, or 3.

This being the case, in the synchronous detection means, the following arithmetic operations are performed:

$$I_N' = I_{det}\cos\omega_N't+Q_{det}\sin\omega_N't \quad (9)$$

$$Q_N' = I_{det}\sin\omega_N't-Q_{det}\cos\omega_N't \quad (10)$$

First, to obtain the channel-corresponding decoded data I_1' and Q_1' in the first channel (C1),

$$\omega_N' = \omega_N-\omega_C \quad (11)$$

is substituted for the angular frequency ω_N' of equations (9) and 10). In this case, since N = 1, $\omega_1-\omega_C$ is substituted for ω_N'.

This being the case, then for the I_{ch} data I_1', equation (9) becomes as shown in the following equation (12):

$$I_1' = 0.5\cos(\omega_1-\omega_C)\ [\{I_1\cos(\omega_1-\omega_C)t-Q_1\sin(\omega_1-\omega_C)t\}$$
$$+ \{I_2\cos(\omega_2-\omega_C)t-Q_2\sin(\omega_2-\omega_C)t\}$$
$$+ \{I_3\cos(\omega_3-\omega_C)t-Q_3\sin(\omega_3-\omega_C)t\}]$$

$$
\begin{aligned}
&+ 0.5 \sin(\omega_1-\omega_c) [\{I_1\sin(\omega_1-\omega_c)t+Q_1\cos(\omega_1-\omega_c)t\} \\
&+ \{I_2\sin(\omega_2-\omega_C)t+Q_2\cos(\omega_2-\omega_C)t\} \\
&+ \{I_3\sin(\omega_3-\omega_C)t+Q_3\cos(\omega_3-\omega_C)t\}] \qquad (12)
\end{aligned}
$$

Further, for Q_{ch} data Q_1', the above equation (10) becomes the following equation (13):

$$
\begin{aligned}
&+ 0.5 \sin(\omega_1-\omega_c)t [\{I_1\cos(\omega_1-\omega_c)t-Q_1\sin(\omega_1-\omega_c)t\} \\
&+ \{I_2\cos(\omega_2-\omega_C)t-Q_2\sin(\omega_2-\omega_C)t\} \\
&+ \{I_3\cos(\omega_3-\omega_C)t-Q_1\sin(\omega_1-\omega_C)t\} \\
&- 0.5 \cos(\omega_1-\omega_c)t [\{I_1\sin(\omega_1-\omega_c)t-Q_1\cos(\omega_1-\omega_c)t\} \\
&+ \{I_2\sin(\omega_2-\omega_C)t+Q_2\cos(\omega_2-\omega_C)t\} \\
&+ \{I_3\sin(\omega_3-\omega_C)t+Q_3\cos(\omega_3-\omega_C)t\}] \qquad (13)
\end{aligned}
$$

The above equation (12), however, is further developed to the following equation (14):

$$
\begin{aligned}
&= 0.25 [\{I_1(\cos2(\omega_1-w_c)t+\cos(0)) \\
&-Q_1(\sin2(\omega_1-\omega_C)t+\sin(0))\} \\
&+\{I_2(\cos(\omega_1+\omega_2-2\omega_C)t+\cos(\omega_1-\omega_2)t) \\
&-Q_2(\sin(\omega_1+\omega_2-2\omega_C)t+\sin(\omega_1-\omega_2)t\} \\
&+\{I_3(\cos(\omega_1+\omega_3-2\omega_C)t+\cos(\omega_1-\omega_3)t) \\
&-Q_3(\sin(\omega_1+\omega_3-2\omega_C)t+\sin(\omega_1-\omega_3)t\} \\
&+0.5[\{I_1(-\cos2(\omega_1-\omega_C)t+\cos(0)) \\
&+Q_1(\sin2(\omega_1-\omega_C)t+\sin(0))\} \\
&+\{I_2(-\cos(\omega_1+\omega_2-2\omega_C)t+\cos(\omega_1-\omega_2)t) \\
&+Q_2(\sin(\omega_1+\omega_2-2\omega_C)t+\sin(\omega_1-\omega_2)t\} \\
&+\{I_3(-\cos(\omega_1+\omega_3-2\omega_C)t+\cos(\omega_1-\omega_3)t) \\
&+Q_3(\sin(\omega_1+\omega_3-2\omega_C)t+\sin(\omega_1-\omega_3)t\} \\
&= 0.25 [2I_1+2I_2\cos(\omega_1-\omega_2)t-2I_3\cos(\omega_1-\omega_3)t] \\
&= 0.5 [I_1+I_2\cos(\omega_1-\omega_2)t+I_3\cos(\omega_1-\omega_3)t] \qquad (14)
\end{aligned}
$$

As clear from the final equation of equation (14), the original I_{ch} data I_1 appears as a direct current (DC) component. On the circuit, if the signal component of the frequency $(\omega_1-\omega_2)$ and the signal component of the frequency $(\omega_1-\omega_3)$ are eliminated by a filter etc., the original I_{ch} data I_1 which is sought is decoded.

In the same way, the above equation (13) is further developed to the following equation (15):

$$
\begin{aligned}
&= 0.25\,[\{I_1(\sin 2(\omega_1-\omega_c)t+\sin(0))\\
&-Q_1(-\cos 2(\omega_1-\omega_c)t+\cos(0))\}\\
&+\{I_2(\sin(\omega_1+\omega_2-2\omega_c)t+\sin(\omega_1-\omega_2)t)\\
&-Q_2(-\cos(\omega_1+\omega_2-2\omega_c)t+\cos(\omega_1-\omega_2)t\}\\
&+\{I_3(\sin(\omega_1+\omega_3-2\omega_c)t+\sin(\omega_1-\omega_3)t)\\
&-Q_3(-\cos(\omega_1+\omega_3-2\omega_c)t+\cos(\omega_1-\omega_3)t\}\\
&-0.5[\{I_1(\sin 2(\omega_1-\omega_c)t-\sin(0))\\
&+Q_1(\cos 2(\omega_1-\omega_c)t+\cos(0))\}\\
&+\{I_2(\sin(\omega_1+\omega_2-2\omega_c)t+\sin(\omega_1-\omega_2)t)\\
&+Q_2(\cos(\omega_1+\omega_2-2\omega_c)t+\cos(\omega_1-\omega_2)t\}\\
&+\{I_3(\sin(\omega_1+\omega_3-2\omega_c)t+\cos(\omega_1-\omega_3)t)\\
&+Q_3(\cos(\omega_1+\omega_2-2\omega_c)t+\cos(\omega_1-\omega_3)t\}\\
&= -0.5\,\{Q_1+Q_2\cos(\omega_1-\omega_2)t+Q_3\cos(\omega_1-\omega_3)t\} \qquad (15)
\end{aligned}
$$

As clear from the final equation of equation (15), the original Q_{ch} data Q_1 appears as a direct current (DC) component. On the circuit, if the signal component of the frequency $(\omega_1-\omega_2)$ and the signal component of the frequency $(\omega_1-\omega_3)$ are eliminated by a filter etc., the original Q_{ch} data Q_1 which is sought is decoded. $-Q_1$ may be reversed to Q_1 through an inverter.

Note that the explanation from equation (10) on was made with reference to the first channel (C1), but the above equations (12) to (15) are applied in exactly the same way to the remaining second and third channels, whereby I_2 and Q_2 and I_3 and Q_3 can be obtained.

Figure 5 is a view showing an embodiment of the present invention. In the figure, the general detection means 21 shown in Fig. 3 and the N number of synchronous detection means 22-1, 22-2 ... are positioned at portions given their respective reference numerals.

First, the general detection means 21, as shown, is realized by general orthogonal detectors comprised of two hybrid circuits 41 and 42 and two mixers 43 and 44. The hybrid circuit 42 splits the common local frequency signal L_c into 0° and 90° signals. These two signals are respectively applied to the orthogonal detection mixers

43 and 44.

Between the general detection means 21 and the N number of synchronous detection means 22-1, 22-2 ... is inserted a general low-pass filter means 51 for extracting the signal components having differential frequencies between the frequencies ($\omega 1$, $\omega 2$..) of the carriers (C1, C2...) and the common local frequency signal L_C. The general low-pass filter means 51 can be constituted by a general low-pass filter.

Using this general low-pass filter means 51, the high frequency component ($\omega_N+\omega_C$) (N=1, 2...) shown in equations (5) and (6) is eliminated and the low-pass filtered demodulation signals I_{det} and Q_{det} are obtained. Note that here the analog signals are converted to digital signals. This is done by the analog/digital converting units (A/D) 52. Further, CK is a sampling clock. The positions of the A/D's are not limited to those illustrated.

The N number of synchronous detection means (22-1, 22-2... 22-N shown in Fig. 3) are constituted by the above-mentioned endless phase shifters (45-1, 45-2... 45-N).

The endless phase shifters 45-1, 45-2... 45-N commonly receive the outputs detected generally and orthogonally by the general detection means 21 through the general low-pass filter means 51 and perform complex arithmetic operations to multiply the in-phase component and quadrature component of the generally and orthogonally detected outputs with the $\sin\omega t$ and $\cos\omega t$. Here, the angular frequency ω has a value proportional to the N number of differential frequencies. These complex arithmetic operations are explained using the previously mentioned equation (9), equation (10), equation (12), and equation (13). Therefore, the angular frequency ω corresponds to the ω_N' shown in equation (11) (see ω_1', ω_2'... ω_N' in Fig. 3), that is, $\omega_N' = \omega_N-\omega_C$ (N = 1, 2 ...)

Figure 6 is a view showing a specific example of an

endless phase shifter. In the figure, the endless phase shifter 45 is comprised of four multipliers 46 and an adder 47 and subtractor 48. The arithmetic operations are as shown in the previously mentioned equations (9) and (10). Note that in the figure, ω corresponds to the ω_N' in equations (9) and (10) ($N = 1, 2...$)

Returning to Fig. 5, provision is made of N number of discrete low-pass filter means 55-1, 55-2... 55-N for extracting the corresponding original data from the endless phase shifters 45-1, 45-2...45-N. Further, provision is made of a data synthesizer means 56 for successively taking out the outputs from the discrete low-pass filter means to reproduce the original data. The data synthesizer means 56 is constituted by an ordinary discriminator and parallel/serial converter.

The discrete low-pass filter means 55-1, 55-2... 55-N can be constituted by general low-pass filters and perform the role of eliminating the signal components of the frequency ($\omega_1-\omega_2$) and frequency ($\omega_1-\omega_3$) from equations (14) and (15) and taking out the original data I_1 and Q_1.

In the embodiment of Fig. 5, there are N number of carrier recovery units (CR) 61-1, 61-2... 61-N outputting the N types of sinωt and cosωt in response to the outputs of the N number of discrete low-pass filter means 55-1, 55-2...55-N. The "N types of sinωt and cosωt" spoken of here means the $\sin\omega_N' t$ and $\cos\omega_N' t$ expressed by the ω_N' in equation (11), where N is 1, 2...

As the carrier recovery unit (61), for example, use may be made of a known reverse-modulation type carrier recovery circuit, for example, but it is necessary to break down the output of a VCO (voltage controlled oscillator) at the final stage of the reverse-modulation type carrier recovery circuit to the sin component and cos component and apply the same to the endless phase shifter. The simplest method for this is considered to be use of a ROM. The ROM would store the pairs of sin component data and cos component data corresponding to the outputs of the VCO in advance and

output the corresponding sin component data and cos component data by using the VCO output as an address input.

In the embodiment of Fig. 5, transversal equalizer units (T•EQL) 71-1, 71-2...71-N are inserted between the N number of discrete low-pass filter means 55-1, 55-2...55-N and the N number of carrier recovery units 61-1, 61-2... 61-N.

It is not absolutely necessary to provide the transversal equalizer units, but carrier recovery and data decoding can be performed faster and with greater accuracy by equalization of the waveform by the transversal equalizer units.

Further, bit timing recovery units (BTR) 72-1, 72-2...72-N for specifying the operating timings of the transversal equalizer units 71-1, 71-2...71-N are provided at the output sides of the discrete low-pass filter means 55-1, 55-2... 55-N. The bit timing recovery units are used to perform the sampling at a time where the so-called eye pattern is most open.

In the embodiment of Fig. 5, analog/digital converters (A/D) 52 were provided between the general detection means 21 and the synchronous detection means 22-1, 22-2... 22-N, but they may also be inserted in the signal lines corresponding to the position shown by A/D•1 and the position shown by A/D•2 in Fig. 5.

As clear from Fig. 5, the synchronous detection means 22-1, 22-2...22-N involve hardware provided for each channel (carrier). Therefore, it is preferable to design the hardware portions for the N number of channels to be as suitable for LSI as possible. To facilitate this, then at least at the stage before the hardware portion for the N number of channels it is desirable to convert to digital signals. This being the case, it is preferable to provide the analog/digital converters 52 (for example, A/D•1) toward the transmitter side from the

inputs of the synchronous detection means (22).

Thus, in the illustrated embodiment of the present invention, provision is made of a single orthogonal detection unit commonly used for all the channels (carriers C1, C2, ...CN) at the initial stage of the receiver side, which enables the amount of hardware to be reduced. After this single orthogonal detection unit, in subsequent stages, hardware must be provided for each channel, but this channel-corresponding hardware (EPS, CR, BTR, EQL, etc) is extremely easy to put on an LSI chip with current technology, so the percentage of that hardware in the overall amount of hardware is small.

CLAIMS:

1. A multi-carrier demodulator, for demodulating a received signal that is a combination of N carrier signals that are modulated respectively with N sets of data derived from an original data sequence, comprising:

intermediate detector circuitry employing a common local frequency signal to derive, from the said received signal, an output containing N signal components having respective different signal frequencies;

N synchronous detection stages connected to receive the said output and operable to employ respective reference signals, having frequencies equal to the said respective different signal frequencies, to subject that output to synchronous detection so as to provide respective detected signals; and

data synthesising circuitry connected to employ the said detected signals to reproduce the said original data sequence.

2. A demodulator for multi-carrier modulation signals in a system wherein N (N being an integer of at least 2) number of carriers are modulated with N number of original data in one-to-one correspondence, these are synthesized to obtain a multi-carrier modulation signal which is transmitted from a transmitter side, and this multi-carrier modulation signal is received at a receiver side and demodulated to reproduce the original data,

said demodulator for multi-carrier modulation signals being provided with:

a general detection means for detecting the received multi-carrier modulation signal generally by a common local frequency signal and

N number of synchronous detection means for receiving in common the output from said general

detection means and performing synchronous detection by N number of differential frequencies between the frequencies of the N number of carriers and the frequency of the common local frequency signal and

reproducing the original data by the said N number of synchronous detection means.

3. A demodulator for multi-carrier modulation signals as set forth in claim 2, wherein said general detection means and said N number of synchronous detection means having inserted between them general low-pass filter means for extracting signal components having differential frequencies between the frequencies of the carriers and the frequency of the common local frequency signal.

4. A demodulator for multi-carrier modulation signals as set forth in claim 3, wherein the N synchronous detection means commonly receive the output generally and orthogonally detected by said general detection means through said general low-pass filter means and perform complex operations to multiply the in-phase component and quadrature phase component by the generally and orthogonally detected output with $\sin\omega t$ and $\cos\omega t$, said angular frequency ω having a value proportional to said N number of differential frequencies.

5. A demodulator for multi-carrier modulation signals as set forth in claim 2, 3 or 4, wherein provision is made of N number of discrete low-pass filter means for extracting from the outputs of the N synchronous detection means the corresponding original data and a data synthesizer means for successively taking out the outputs from the discrete low-pass filter means and reproducing the original data.

6. A demodulator for multi-carrier modulation signals as set forth in claim 5 read as appended to claim 4, wherein provision is made of N number of

carrier recovery units which output N types of said sinwt and coswt in response to the outputs from the N number of discrete low-pass filter means.

7. A demodulator for multi-carrier modulation signals as set forth in claim 6, wherein said N number of discrete low-pass filter means and said N number of carrier recovery units have inserted between them transversal equalizer units.

8. A demodulator for multi-carrier modulation signals as set forth in claim 7, wherein bit timing recovery units for defining the operating timings of the N number of transversal equalizer units are provided at the output sides of the N number of discrete low-pass filter means.

9. A demodulator for multi-carrier modulation signals as set forth in any preceding claim, wherein the N number of synchronous detection means are comprised of endless phase shifters.

10. A demodulator for multi-carrier modulation signals as set forth in any preceding claim, wherein provision is made of analog/digital converters for converting analog signals to digital signals.

11. A demodulator for multi-carrier modulation signals as set forth in claim 10, wherein said analog/digital converters are provided toward the transmitter side from the inputs of the N number of synchronous detection means.

12. A multi-carrier demodulator, substantially as hereinbefore described with reference to Fig. 5, or Figs. 5 and 6, of the accompanying drawings.

Patents Act 1977 Examiner's report to the Comptroller under Section 17 (The Search report) - 18 -	Application number GB 9401790.2
Relevant Technical Fields (i) UK Cl (Ed.M) H4P (PAL, PAFD) H4L (LDB) (ii) Int Cl (Ed.5) H04L (27/14)	Search Examiner VICKI STRACHAN Date of completion of Search 8 APRIL 1994
Databases (see below) (i) UK Patent Office collections of GB, EP, WO and US patent specifications. (ii)	Documents considered relevant following a search in respect of Claims :- 1 TO 12

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